EXPERIMENTS ON FECHNER'S PARADOXON.

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Psychology, at least at an earlier period of its history, has had to defend its claim to be considered as an exact science. The best defense of this claim consists in showing that not only are many of its problems insoluble for physics and physiology, but that for these sciences they are not problems at all. The first of the general questions of experimental psychology is that of the quantitative relation between an external excitation and the corresponding internal reaction or sensation. One of the most interesting phases of this question concerns those cases where the constituting parts of the stimulus are applied to different though coördinate sensitive surfaces, *e. g.*, in the case of the organs of sight. The present article deals with the relation of the light intensity of an object seen with both eyes to that of the same object seen with only one. Its purpose is to give a brief account (1) of the work previously done upon this problem, (2) of the writer's own work upon it.

I.

The first investigation of this problem was undertaken nearly a century and a half ago by Jurin, who found by experiment that an object appears measurably brighter regarded with both eyes than with only one. His method may be schematically illustrated by Fig. 1.

A sheet of white paper, P, was illuminated by two candles, L_1 and L_2, placed behind it. A screen, S_1, was interposed in such a way that the right half of the paper received the light of both candles, the left half only the light of one. A

second screen, S_2, was placed before the right eye of the observer in such a way as to hide from it the brighter half of the paper. The left, or less illumined half, was now seen by both eyes, and the right, or brighter half, only by the left eye. It was found that the left, or darker half, seen with both eyes, appeared about equally bright with the right, or brighter half, seen with the left eye, when the one light was about 3.4 times as far distant as the other, so that the intensities of the brighter and the darker halves bore to each other the relation

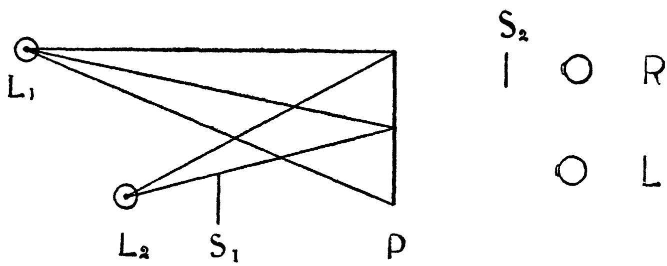

FIG. 1.

of 13 to 12. According to this result, the same object, or one equally bright, would appear in binocular vision $\frac{1}{13}$ brighter than in monocular vision.

The problem was dealt with by a somewhat more accurate method by H. H. Valerius in 1873, by means of an application of Faucault's photometer. This photometer consists of a box, the interior of which is lined with black cloth to prevent the reflection of light rays. In one end of the box is a semi-transparent glass disc, placed so as to admit the lights whose intensities are to be compared. The box contains a sliding diaphragm, which, by means of a screw, can be placed nearer to or further from the disc. The lights to be compared are now placed one on each side of the diaphragm, in such a way that by adjusting the distance of the diaphragm from the disc, each light illumines exactly one-half of the disc. The observer, looking from the outside at the disc, adjusts the distances of the two lights from the halves of the disc which they respectively illuminate, so that the whole surface of the disc appears equally bright.

Then these distances are measured and the relative intensities of the light determined by the rule that they will be inversely as the squares of their distances from the illuminated object. Since Valerius has not illustrated his article by diagrams, it may be worth while to attempt a schematic representation of his arrangement in Fig. 2.

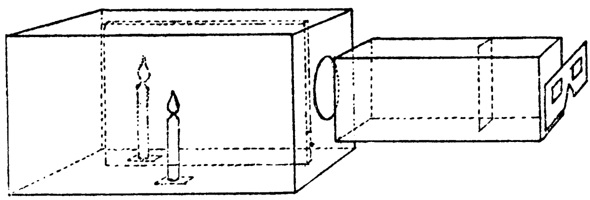

FIG. 2.

The mode of using this apparatus in the experiments of Valerius was as follows: The two lights were introduced as though their intensities were to be compared and adjusted, so that the whole surface of the disc was equally illuminated and their distances noted. The observer looks through the tube, keeping the position of the head constant by means of a screen, with openings for the eyes and a slit for the nose. In the interior of the tube is a diaphragm, which conceals one of the vertical halves of the disc from one of the eyes of the observer. The result is that one of the vertical halves of the disc is seen with both eyes, the other with only one. When this is the case, the half seen only with one eye appears less bright than the other. This is remedied by moving the light which illumines the former nearer to the disc, until the two halves again appear equally bright. This new distance is also measured and compared with the former distance of the same light. Now, if we denote by I the brightness of the half of the disc under consideration when the light is at the first distance d, and by J the brightness when the light is at the lesser distance d', there is between J and I the relation $J:I::d^2:d'^2$, and, consequently, since the intensity I of the light seen with both eyes is equal to the intensity J of the same light seen with one eye, we have as an expression of the relation of the light intensities of binocular and

monocular vision the ratio $d^2 : d'^2$. The following is Valerius' statement of his experiments and their results :

FIRST SERIES, MADE WITH THE FLAMES OF TWO CANDLES.

Distance of Right Candle from Right Half of Disc.	Second Distance.	Relation of the Two-Light Intensities.
100 Ctm.	94 Ctm.	1.15
75 "	71 "	1.11
62 "	53 "	1.14
41 "	38 "	1.16

SECOND SERIES MADE (BY ANOTHER OBSERVER) WITH TWO GAS FLAMES.

Distance of Right-Hand Flame from Right Half of Disc.	Second Distance.	Relation of the Two-Light Intensities.
100 Ctm.	94 Ctm.	1.13
75 "	71 "	1.11
62 "	57.5 "	1.16
41 "	47.5 "	1.18

From these results Valerius draws the following conclusions : 1. The relation of the light intensities of the same object, observed successively with one eye and with two, appears to be almost entirely independent of the absolute intensity. 2. For weak lights, such as those of the ordinary candle or gas flame, this relation does not vary much from 1.15.

These early experiments, though scientific in principle, are defective in several respects.

1. The methods of both Jurin and Valerius are open to the objection, which Valerins afterwards noticed, that the sensitiveness to light of the two eyes of the same individual is commonly not the same, and this may materially affect the result.

2. The two eyes were not, in the experiments, subjected to the same treatment. One eye received continuously more light than the other.

3. Though the object observed was screened from one eye, much light was still admitted to that eye, a fact that would doubtless have an influence on the intensity of the whole.

4. The trials were not sufficiently numerous or varied to

warrant the conclusion of Valerius that the relation does not depend on the absolute intensity, nor does that conclusion seem to be borne out by the trials that were made; for the relation seems to vary with the absolute intensity, though there is not much constancy in the results. Another consideration overlooked by Valerius was that it is only possible for the absolute intensity to affect the relation if the first impression both of the one eye and the two are taken, for after the observer has looked for some time at the object, the eyes become adapted to the absolute intensity, so that it can no longer affect the relation.

5. It would appear that both Valerius and Jurin fix the relation too exactly, because they take no account of the subjective conditions on which the results of their experiments must in large measure depend; for we are not comparing absolute light intensities, but only the intensity of light sensations.

Fechner made, in 1860, some experiments at Leipsic, from which it appeared that with most observers the closing of one eye caused a slight darkening of the whole visual field, followed immediately, however, by a restoration of its brightness, whence he concluded that the intensities of monocular and binocular vision are equal. Aubert, however, following the method of Fechner, found that the light intensity of the whole visual field was somewhat greater when both eyes were open than when one was closed, provided that the absolute intensity were not greater than that of white paper in diffused daylight. These experiments do not, however, possess much value for the solution of our problem (viz., to find how much the intensity of monocular vision is increased by the addition of the other eye), because they seem to have been made with reference to continued observation both in binocular and monocular vision, where the one eye, becoming accustomed to working alone, is not in the same condition as if the first impressions had been taken.

In the course of further trials, under different conditions, however, Fechner found: (1) That when the visual field of one eye is darkened by means of a smoked glass, and then the common visual field, or a white object in the common

visual field, is regarded, the latter appears darker than if the eye partially obscured by the glass is closed. (This, Fechner calls the "paradox trial," because the total darkening of one retina causes a brightening of the whole visual field.) (2) That an equal darkening of the common visual field results from placing before one eye a glass which absorbs very little or one which absorbs very much light. This equal darkening of the whole visual field, by unequal components, Fechner calls the conjugate intensities. With a certain light absorption occurs the maximal darkening of the whole vision; this point Fechner calls the minimum point.

In these experiments the darkening continued for some seconds, so that its extent could be estimated. But if the glass before one eye were very dark, and the observer continued to look, for say a minute, there occurred an alternate darkening and brightening, the so-called competition phenomenon of the visual fields. For this reason Hering regards Fechner's trials solely as instances of the competition phenomenon. Helmholtz, on the other hand, holds that in these trials we have not a change in the sensation of brightness, but only a change in our judgment regarding the surface-color of the white object. Aubert rejects both these views as inconsequential, though he admits that the use of an object with strongly marked lines or contours has naturally a disturbing effect upon the simplicity of the light sensation. According to Aubert the trials show that a combination of the sensations of the two retinas occurs when the difference of their intensities does not go beyond a certain point, which the experiments themselves must determine, but beyond this point the capability of combination decreases and finally ceases altogether. He thinks, also, that the absolute intensity of the object affects the possibility of combination.

In the similar experiments made by Aubert himself, a double episkotister was used, having fixed before it a screen with openings for the two eyes of the observer. One disc corresponds to the lighter smoked glass of Fechner, the other to the darker. The episkotister has the advantage of giving an exact determination and variation of the intensity,

and also of furnishing an absolutely colorless grey, while the smoked glasses have almost always a certain color, which makes it extremely difficult to compare their intensities. The greatest darkening in the common visual field occurred in Aubert's experiments, when one eye was free and $\frac{122}{1000}$ of the full light was admitted to the other; *i. e.*, if the intensity of the full light = 1,000 when a light of the intensity of 122 is admitted to one eye while the other is unobscured. On the admission of less light, the common visual field appeared brighter, and the same result followed on the admission of more light. There must, therefore, be found total intensities which are equal to each other when one eye looks through a disc, which admits say 55 parts of light, or through one which admits say 500. Fechner represents these numbers on a curve, the shortest ordinate of which corresponds to the greatest darkening in the common visual field; the lowest resulting point of the curve he calls the minimum-point, the equal intensities in the common visual field upon the greater and less darkening of the one eye the conjugate points of the curve. This mode of representation, with the modification required by the slightly different results of Aubert, may here be reproduced in Fig. 3.

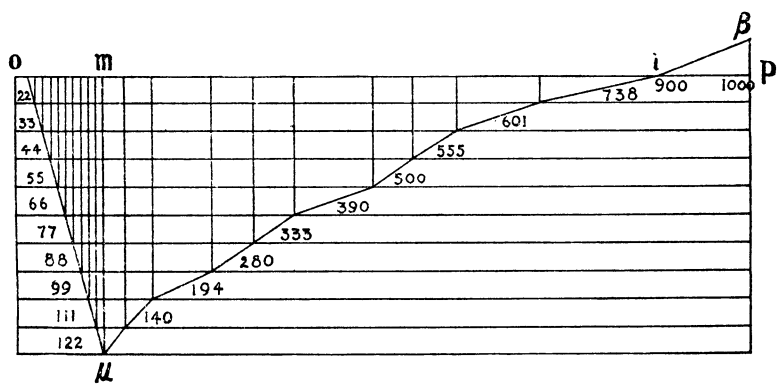

FIG. 3.

op. represents the intensity of the light sensation of the whole visual field when one eye is closed. The point β of the ordinate above *op.* represents the somewhat greater intensity when both eyes are open, which, according to Aubert,

makes a difference of about $\frac{1}{10}$, rather more than Valerius or Jurin found it; μ, the lowest point of the curve, represents the minimum-point, which corresponds to the sensation of least light in the common visual field when one eye is unobscured. This point was reached when for the other eye 0.122 of the full light was admitted by the episkotister, and the darkening of the whole visual field was then as great as when with monocular vision 0.583 of the full light was admitted. These numbers Aubert found to be somewhat different when, instead of a sheet of white paper in diffused daylight, he took as objects, successively, the sky, the white glass shade of a lamp and the free lamp flame. His results concerning the conjugate intensities may be given in the following table corresponding to Fig. 3.

Paper.	White Glass Shade.	Sky.	Free Flame.
22 = 738	16 = 750	16 = 700	16 = 444
33 = 601	22 = 666	22 = 500	22 = 377
44 = 555	33 = 400	33 = 333	33 = 333
66 = 390	44 = 333	44 = 128	44 = 250
77 = 333	55 = 250	55 = 83	55 = 200
88 = 280	66 = 166	66	(66 - - - 166)
99 = 194	(77 - - - 140)	(333)	
111 = 140			
122 = (417)			

In explanation of the general phenomena of the coöperation of the two eyes, there are, according to Fechner, three theories.

1. The combination theory, according to which the total intensity equals the sum of the monocular intensities, where this sum is subject, of course, to the same condition as all summation of intensities (*i. e.*, Weber's law). This theory agrees with the fact that the intensity of binocular vision is not double that of monocular, but it does not explain why under certain circumstances a decrease of physical intensity causes an increase of intensity in sensation.

2. Theory of attention. According to this theory, in the case of smaller differences of the impressions, the attention is distributed upon both the impressions, while in the case of greater differences the attention is directed exclusively to the

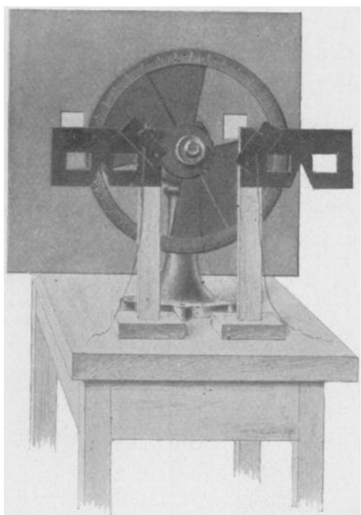

FIG. 4.

brighter retinal image. This is the theory which seems to be favored by Aubert. It may be objected that the same thing should hold good in the different parts of one retinal image, where all parts are not equally bright, *i. e.*, the brighter part should monopolize the attention to the exclusion of the other. Further, it is an error to speak of the two retinal images as if they existed separately in consciousness. In our perception there exists only *one* visual field. That we regard *two* similar images in this visual field sometimes as belonging to two similar objects, and at other times as double images of the same object, does not depend on the intensities of these images.

3. Theory of antagonism. This is Fechner's own theory. It explains the phenomenon as coming under the general phenomenon of competition of the visual fields. According to this view, the impressions of the two eyes are combined when the difference of intensity and quality are not very great, while in the case of greater differences no combination takes place, but either the one of the images (generally the less bright) is suppressed entirely, or the two images replace each other alternately.

The above is a short résumé, so far as the literature of the subject was obtainable by me. The following are the references: Valerius, Poggendorff's Annalen, Band CL, p. 317; Jurin, Smith-Kästner, Lehrbegriff der Optik, 1755, p. 479 (Jurin's work is also reported by Aubert); Fechner, Binoculares Sehen, in Abhandlungen der Akadamie in Leipzig, 1860, Band VII, p. 423; Aubert, Physiologische Optik, p. 499, and Physiologie der Netzhaut; Helmholtz, Optique Physiologique, 1st ed. p. 964; Wundt, Physiologische Psychologie, Vol. II, 4th ed., p. 210 ff.

I shall now add an account of some experiments made during the current year in the psychological laboratory of University of Toronto, under the supervision of Dr. Kirschmann.

II

The apparatus employed in this work was a single episkotister turned by an electric motor, as shown in the accompanying cut, Fig. 4.

Behind the episkotister were placed the objects to be observed. In a large sheet of black card-board two square holes, 3½ ctm. square, were cut and covered with white tissue paper, and behind each opening was placed alternately an incandescent lamp of 32-candle power. The intensity of the light was varied by using more or fewer sheets of tissue paper. The episkotister was graduated in 360°, and was arranged so as to vary the light admitted between the limits of 0° and one-half the total intensity (=180°). The illuminated squares were placed in line with the edges of the disc, one on the right hand, the other on the left. In front of the disc were two screens with openings for the two eyes of the observer, and slits for the nose in order to keep the head steady. These screens were placed so that through one of them the right hand light was seen, through the other the left, and were also arranged in such a way that by means of them one eye saw the light through the episkotister, the other looked directly at it. The small shutters shown in the cut were used to cover the eye, for which the light was partially obscured by the episkotister. During the experiment all other light than that of the electric lamp in use in the experiment, was carefully excluded from the room. In the use of the *two* objects and *two* screens there was a double purpose: (1.) To avoid possible errors due to a difference between the two eyes of the observer. (2.) To subject both eyes throughout the experiments to the same treatment, and so to avoid another source of error.

Before describing the method adopted in the experiments, it is necessary to more clearly define their object. There are two questions which do not seem to have been clearly distinguished by former investigators: (1.) The question, to what extent an object appears brighter or darker accordingly as it is continuously regarded under similar conditions with two eyes or with one. Here we have to do with a continuous state in coöperation or non-coöperation. (2.) The question, how much intensity of light sensation is added to that of monocular vision by the addition of the other eye, or subtracted from that of binocular vision by the closing of one eye? Here we deal with the immediate effect of a change. Viewing the

problem from the first standpoint, we have to seek for an equation between binocular and monocular intensities. From the other standpoint the problem presents itself as follows: For every intensity in monocular vision there exists a certain other intensity, the admission or non-admission of which to the other eye has *no effect* on the total intensity. To find for some cases these physical intensities, which, as far as it concerns the intensity of light sensation, are entirely ineffective, is the purpose of our experiments.

Fechner's paradox trial had shown that if one eye were partially obscured by a smoked glass or similar means, there occurred a brightening of the whole vision field when that eye was closed. It appeared, however, from some preliminary trials, that this is only true if a glass is used which absorbs most of the light. On the other hand, if a glass or episkotister is used, which absorbs comparatively little light, on the closing of the one eye the whole visual field appears darker. Between these limits, therefore, there must be, corresponding to Aubert's and Fechner's minimum-point, an indifference point, where no difference will appear in the intensity of the common visual field, or of an object in the common visual field on the closing of the one eye. To find this point, then, was the object of these experiments.

Placing himself before the left-hand screen of our apparatus with his eyes to the openings, the observer looks at the white square with the left eye free and the right eye darkened by the episkotister, admitting only a few degrees of light. After looking for a moment he pulls the string attached to the slide, thus shutting off the object entirely from the right eye, and immediately reports whether the object looks more or less or equally bright. Then changing over to the right-hand screen, he repeats the trial, having now the right eye free and the left partially obscured. Then the episkotister is readjusted so as to admit a little more light and the trials made again, beginning this time on the right side and changing over to the left, and so on through all the degrees of light between the two extremes. It was usually found that the indifference point did not occur upon the admission of one particular degree of light, but usually extended over a considerable

number of degrees, and that often when the object had begun to appear darker or brighter, it would, upon a further change, again seem equal. At the conclusion of a series of trials the average of the equal points was taken as representing the indifference point for that series. And where, as sometimes happened, there was a sudden change from brighter to darker, a point midway between was taken as the "equal" point. All the trials were made under similar conditions by two observers. In order to vary the conditions as much as possible, one series was made beginning with the episkotister admitting 5° of light and proceeding upwards to 180°, the next proceeding from 180° to 5°, the next beginning within the limits of the "equal" points and proceeding both up and down till those limits were passed, and then going back again to the region of equality. Different absolute intensities were used and a series of trials made for each, the intensity being varied, as already said, by placing more or fewer sheets of tissue paper over the apertures. There was found to be a variation in the results in close correspondence with the variations in the absolute intensity, as shown in the accompanying table. Some supplementary trials were also made with pure colors, the results of which are also appended. In the table the absolute intensity used in the first series of trials (that of a 32, candle power lamp behind two sheets of tissue paper) is taken as 360°, and the others in comparison with it, and measured by means of an episkotister photometer.[1]

In the case of the observer K the results for the two sides were so different that they had to be given separately. The two eyes of the observer K, although in the same state refractively, are in several respects considerably different. The left eye has an iris of different color and a considerably smaller pupil than the right. With the other observer,

[1] If one tissue paper allows $(\frac{1}{n})$ of the incident light to pass, then through 2 papers $(\frac{1}{n})^2$ should be transmitted, through m papers, $(\frac{1}{n})^m$, according to the theory. By photometrical measurement the transmission through several sheets is always found to be a little greater than the computed value. This is due to the circumstance that by the contact of the different sheets the number of absorbing and diffuse-reflecting surfaces is diminished.

the combined results of the two eyes are given, though in this case, also, a difference was noticeable, though smaller and less constant.

TABLE I.

EXPERIMENTS WITH WHITE LIGHT.

Number of Tissue Papers.	Photometrically Determined Intensity.	OBSERVER: K.						OBSERVER: R.		
		LEFT SIDE.			RIGHT SIDE.			LEFT AND RIGHT SIDE.		
		Av. Value.	m.V.	Ratio of the Full Light.	Av. Value.	m.V.	Ratio of the Full Light.	Av. Value.	m.V.	Ratio of the Full Light.
2	360	$52\frac{35}{72}^{\circ}$	$4\frac{1}{72}^{\circ}$	0,146	$67\frac{2}{3}^{\circ}$	$\frac{13}{15}^{\circ}$	0,188	$63\frac{257}{352}^{\circ}$	$7\frac{345}{352}^{\circ}$	0,177
4	210	$62\frac{47}{54}^{\circ}$	$\frac{87}{162}^{\circ}$	0,175	$73\frac{11}{69}^{\circ}$	$2\frac{77}{135}^{\circ}$	0,203	$77\frac{57}{1820}^{\circ}$	$2\frac{671}{1820}$	0,214
6	120	$67\frac{13}{21}^{\circ}$	$9\frac{1}{21}^{\circ}$	0,188	$76\frac{2}{3}^{\circ}$	0°	0,213	$99\frac{11}{16}^{\circ}$	$5\frac{5}{16}^{\circ}$	0,277
10	12(?)	$77\frac{6}{7}^{\circ}$	$\frac{6}{7}^{\circ}$	0,216	$106\frac{19}{36}^{\circ}$	$\frac{35}{36}^{\circ}$	0,296	$121\frac{15}{32}^{\circ}$	$4\frac{13}{32}^{\circ}$	0,337
10 and 2 sheets of ord'y white paper.	1	$127\frac{1}{2}^{\circ}$		0,354	$132\frac{1}{2}^{\circ}$		0,368	165°	5°	0,458

TABLE II.

EXPERIMENTS WITH COLORED LIGHT.

Color.	OBSERVER: K.						OBSERVER: R.		
	LEFT SIDE.			RIGHT SIDE.			LEFT AND RIGHT SIDE.		
	Av. Value.	m.V.	Ratio to the Full Light.	Av. Value.	m.V.	Ratio to the Full Light.	Av. Value.	m.V.	Ratio to the Full Light.
Red	$83\frac{1}{8}^{\circ}$	$3\frac{1}{8}^{\circ}$	0,231	$98\frac{11}{18}^{\circ}$	$3\frac{11}{18}^{\circ}$	0,274	$110\frac{5}{12}^{\circ}$	5°	0,307
Green	$100\frac{5}{6}^{\circ}$		0,280	$123\frac{1}{3}^{\circ}$		0,343	$92\frac{3}{56}^{\circ}$	$\frac{45}{56}^{\circ}$	0,256
Blue	$95\frac{5}{17}^{\circ}$	$5\frac{5}{17}^{\circ}$	0,265	$106\frac{13}{22}^{\circ}$	$3\frac{9}{22}^{\circ}$	0,296	$118\frac{1}{2}^{\circ}$	$1\frac{1}{2}^{\circ}$	0,329

In Table I the numbers given as "average-values" represent the number of degrees of the episkotister, through which the light had to pass in order to produce no effect on the total intensity. These numbers are attained by averaging, in the case of observer K, the results of two double series of experiments; in the case of observer R, of four double series.

The second table contains the results of a few experiments with colored light. In these experiments the two openings

which served as objects were covered with a combination of tissue papers and colored gelatine plates. Three combinations of apparently equal brightness were selected with the help of the spectroscope. The one permitted the transmission of the red end of the spectrum only, up to the line D, while the second absorbed all light at the ends of the spectrum, allowing only the transmission of the rays between D and F, and the last combination extinguished all rays less refrangible than F. We found the judgment in the case of colored light more difficult and uncertain; the region of equality is distributed over a larger field. There is a remarkable difference between the two observers. For K the greatest average value is found in green, where R has the smallest. If differences in the intensity of our colors, which could not be entirely excluded, were the cause, we should expect another result. If our green was brighter than the two other colors, it should have the smallest average value for both observers. But on the other hand it is quite possible that the same color has different values of intensity for different observers.

By *m. V.* we denote in our tables the mean variation, *i. e.*, the difference between the result of the single series and their average. Where the place for the mean variation is left empty in the tables, the results refer to one series of experiments only.

If we now cast a glance at our tables in order to form an opinion on the bearing of our results, we notice that they differ in two points considerably from those of former investigation. *First*, the minimum point of effectiveness of the light applied to the second eye (or in the terms of Fechner and Aubert, the maximal point of obscuration of the common visual field) is found at higher intensities than by former authors on the subject. *Second*, the phenomenon is greatly dependent on the absolute intensity.

Concerning the first point, it is true we have to assume that we should arrive at lower values for the minimum point, if we should proceed to higher intensities than 360°. We should expect that there is an intensity for which the average value of the point of ineffectiveness would show the ratio 0,122 of the full light, as found by Aubert. Of greater importance is

the second point, the dependence of the phenomenon on the absolute intensity. This dependence presents itself in our table I in such an obvious and regular manner that it is astonishing that it could escape the notice of former investigators. But we must not forget that they worked under entirely different conditions. Also the difference in the results of observer K, for left and right side, may have its cause in the different sensitiveness to light of the two eyes.

Remark on the Foregoing Article.

By A. Kirschmann.

The above reported experiments do not claim to be decisive in so far as concerns the absolute values of the minimal point of efficiency, and it is less the intention of the article to solve the problem definitely than to direct attention again to this subject, which touches so many questions of interest in the psychology of the sense of sight. However, this much may be concluded with certainty from these experiments, namely, that the phenomenon referred to is dependent on the absolute intensity. For small absolute brightness the loss of intensity in binocular vision is comparatively greater than for higher intensities; or in other words, the ratio of apparent intensities of an impression in monocular and binocular vision cannot be considered as constant. A few remarks will perhaps contribute something to the explanation of the paradox trial in particular, and of the problem of the co-operation of the two eyes in general.

What is the paradox in Fechner's experiment? That a decrease of physical intensity is followed by an increase of intensity in sensation. Or, in our special case, that a certain amount of physical intensity, applied to the one retina, has no effect on the total brightness of the binocular impression. But it does not follow from this that it has *no effect at all.* Its effect goes in another direction. The double eye has not the purpose of increasing the total intensity. Its principal function is to accomplish those parallactic relations which serve as the chief means of depth-perception. If to the

image of one eye that of the other is added, the result is something else than a mere summation of intensities. A part of the physical energy which now reaches the two retinæ will be used to accomplish the new result, the creation of a single image and the projection of it into the third dimension. Now since these parallactic relations, which give rise to our depth-perception, are independent of intensity, the energy needed to produce these effects will not be proportionate to the total energy, but it will in all cases demand a certain amount, below which the effect will not be attained.

Let us call the physical intensity which arrives at the one retina i_1, that arriving at the other i_2, and that physical energy which is at least necessary in order to produce the binocular effect x. Now there are three cases possible. If i_1 and i_2 are both greater than x, in the case of binocular combination, the subtraction of the energy, x, which is needed for this effect, will cause a darkening of the binocular visual field, but the brightness will still be greater than either i_1 or i singly. If x is just equal to one of the monocular intensities, the binocular intensity will be equal to the other monocular. The closing of the eye, in which the image had an intensity equal to x, will then cause the vanishing of the binocular space-effect, but without any change in intensity. This is the case where we have just reached the point of inefficiency. Finally, if one of the monocular intensities, say i_2, is smaller than the minimum value of x, the intensity of the binocular impression, when endowed with three-dimensional properties, will be smaller than i_1, because a part of this physical intensity is needed in order to secure the stereoscopic effect, and the exclusion of the second eye will, by setting free again this part of the energy, be followed by an increase of the light intensity. This is the case in Fechner's paradox experiment. This theory would account quite well for the paradox experiment, but it does not for the conjugate intensities. In order to explain this side of the affair, we have to make the additional assumption that in cases where one of the monocular intensities is very small, while the other is comparatively high, the binocular effect is incomplete or vanishes entirely. The works of previous authors are not quite

clear on this point, but it seems to me quite natural that, if to the one eye is applied the intensity 1, to the other the intensity 0,122, or less than that, the stereoscopic effect is lowered or even excluded. After all it is not necessary that the maximal point of obscuration coincide with our point of least effect on the total of visual field. According to the foregoing remarks, it remains, therefore, a problem of further investigation whether or not the paradox phenomenon takes place equally in the case of real binocular combination with three dimensional properties, and in cases of partly co-inciding double-images.